NEW AMBER DEPOSIT PROVIDES EVIDENCE OF EARLY PALEOGENE EXTINCTIONS, PALEOCLIMATES, AND PAST DISTRIBUTIONS

GEORGE POINAR, JR.

Department of Entomology, Oregon State University, Corvallis, Oregon, USA 97331

BRUCE ARCHIBALD

Department of Biological Sciences, Simon Fraser University, Burnaby, British Colombia, Canada V5A 1S6

and ALEX BROWN

629 Euclid Avenue, Berkeley, California, USA 94708

Abstract

The Canadian Entomologist **131**: 171 – 177 (1999)

A large, previously unstudied amber deposit in British Columbia dating from the Early to Middle Eocene (50–55 Ma) provides a noteworthy new source of terrestrial invertebrates and other life forms. This deposit contains what are likely the earliest unequivocal ants (members of the family Formicidae), including extinct representatives of *Technomyrmex* Mayr 1872, *Leptothorax* Mayr 1855, and *Dolichoderus* Lund 1831. Discovering *Technomyrmex* and a corydiinid cockroach, both of which are currently restricted to tropical regions, confirms earlier evidence of warm paleoclimates and past biogeographic distributions in the early Paleogene. Chemical analysis of the amber indicates that the source tree was an araucarian belonging to or near the genus *Agathis* Salisbury 1807, and demonstrates that this genus survived into the Tertiary in the Northern Hemisphere, since previous records revealed *Agathis* as a component only of the Cretaceous forests in North America. Comparing the Hat Creek fossil assemblages in this deposit with those from the well-studied western Canadian Late Cretaceous amber deposits offers a unique opportunity to study extinction and speciation events on both sides of the Cretaceous–Tertiary boundary.

Poinar G Jr, Archibald B, Brown A. 1999. Extinctions, paléoclimats et répartitions au Paléogène inférieur révélés par l'étude d'un gisement d'ambre. *The Canadian Entomologist* **131** : 171–177.

Résumé

En Colombie-Britannique, un important gisement d'ambre encore jamais examiné et remontant au début-milieu de l'Éocène (50–55 Ma) a mis en lumière une nouvelle source d'invertébrés terrestres et d'autres formes d'organismes. Le gisement contient probablement les plus anciennes vraies fourmis (membres de la famille des Formicidae), dont des représentants maintenant disparus des genres *Technomyrmex* Mayr 1872, *Leptothorax* Mayr 1855 et *Dolichoderus* Lund 1831. La découverte de *Technomyrmex* et d'une blatte corydiinide, tous deux maintenant restreints aux régions tropicales, confirme l'existence de paléoclimats chauds et met en lumière les répartitions biogéographiques telles qu'elles étaient au début du Paléogène. Une analyse chimique a révélé que l'arbre à l'origine de l'ambre est un araucarien appartenant au genre *Agathis* Salisbury 1807 ou à un genre apparenté, et prouve que le genre a survécu jusqu'au Tertiaire dans l'hémisphère nord, puisque des données antérieures ont démontré qu'*Agathis* n'existait que dans les forêts du Crétacé en Amérique du Nord. Par comparaison des associations de fossiles de Hat Creek dans ce gisement à ceux des gisements bien connus de l'ouest canadien à la fin du Crétacé

nous sommes en mesure d'étudier l'histoire des extinctions et spéciations de part et d'autre de la démarcation Crétacé–Tertiaire.

[Traduit par la Rédaction]

Introduction

The Hat Creek coalfield of British Columbia (Fig. 1) spans more that 425 m of strata and contains several hundred million tonnes of sub-bituminous coal, making this one of the largest coal deposits in the world. Amber had been previously collected from various layers of the Hat Creek coalfield, but biological inclusions have never been reported, although the coal has been mined intermittently by a number of companies (Church 1975). On the basis of its inland isolation and general absence of marine or brackish water fossils, the origin of the Hat Creek coalfield is inferred to be a continental (limnic) environment, and probably represented a mixed open forest (Church 1975). Although most of the palynological evidence indicates an age of post-middle Paleocene to Middle Eocene for the coal measures (Hopkins 1980), a potassium–argon date on biotite from rhyolite overlying the sedimentary deposits has provided a minimum age of 51.2 Ma (Church *et al.* 1979). The combined data suggest an Early to Middle Eocene age, or from 50 to 55 Ma, although portions of the coal beds could be older. The present preliminary study was undertaken to determine the range of biota that could be found in the amber, to identify the plant group responsible for the formation of the amber, and to assess the future implications of the deposits.

Methods

After collecting amber from the coal layers (52°N, 122°W), the material was washed in a lukewarm water bath to remove soil, rock, and coal particles. The amber pieces vary considerably in size, ranging from small particles to larger pieces 3–4 cm in diameter. Most of the amber is almost clear to yellow, and some is white-cloudy and dark red. The inclusions were detected under a dissecting microscope and polishing and sorting was done by hand. Some pieces contain air and water bubbles as well as crystallized residues of plant and invertebrate remains. Samples of Hat Creek amber were submitted for analysis using nuclear magnetic resonance (NMR) spectroscopy. Ant specimens were sent to C. Baroni Urbani (Zoological Institute, Basel, Switzerland) for determination. All of the fossils collected during the present investigation will be deposited in the Kelowna Museum in Kelowna, British Columbia, Canada.

Results

Nuclear magnetic resonance spectroscopy clearly indicates that the fossilized resin originated from trees belonging to the genus *Agathis* Salisbury 1807 (Araucariaceae). This was determined by comparing spectra obtained from Hat Creek amber samples with spectra of recent, semifossilized (copal) and fossilized (amber) deposits of New Zealand which had previously been determined to originate from *Agathis* (Lambert and Shawl, unpublished results 1997; Lambert *et al.* 1993).

A variety of fossils occur in the Hat Creek amber samples (Figs. 2–7). However, it should be emphasized that this was a preliminary study to assess the potential of these deposits for studying aspects of the paleoecology and paleoclimatology of this Eocene forest. From approximately 5000 pieces of amber from Hat Creek which were examined, representatives of the following groups were found: Insecta [Diptera, Coleoptera (Fig. 7), Hemiptera, Blattaria (Fig. 3), Thysanoptera (Fig. 5), Psocoptera,

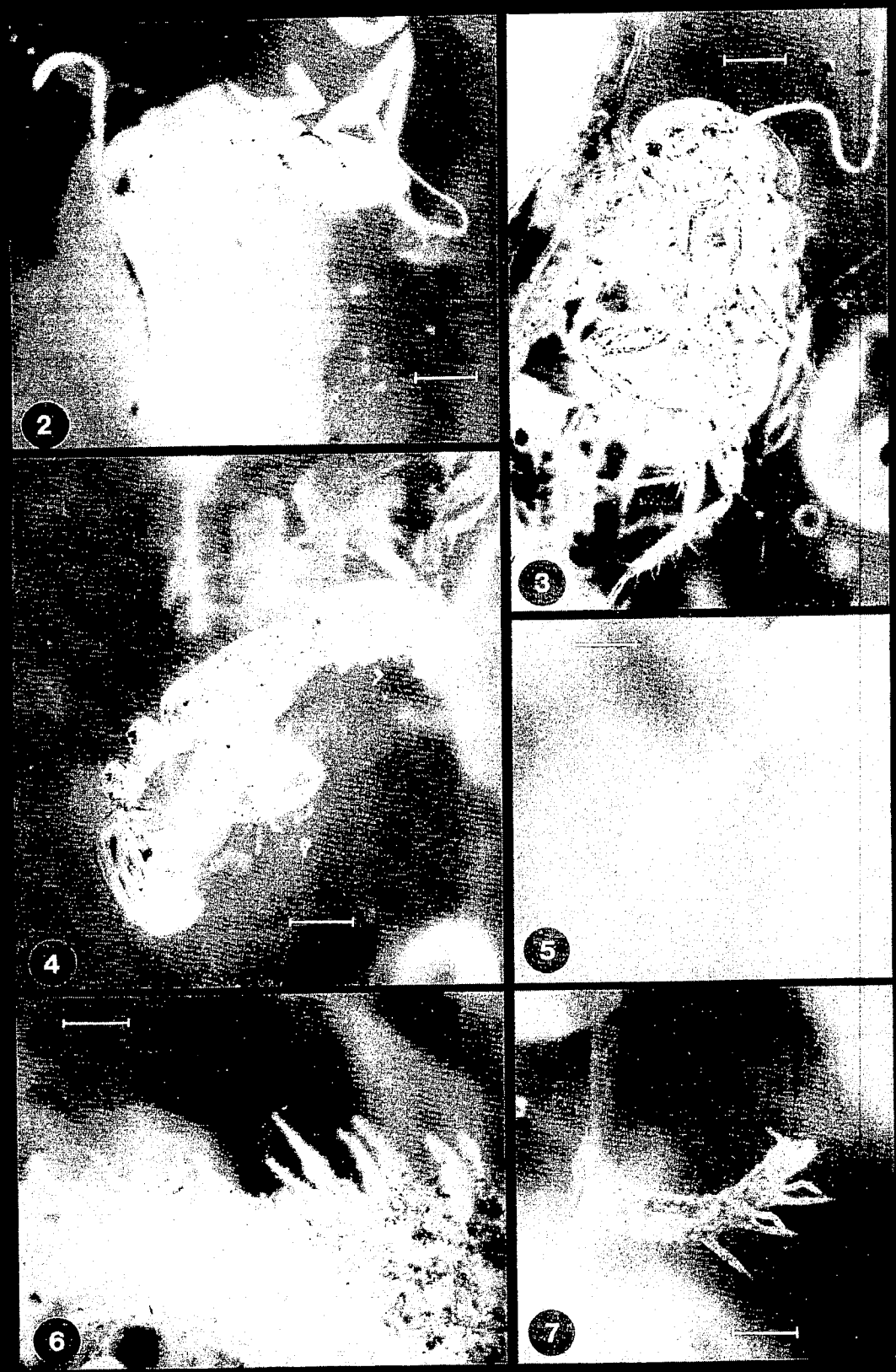
FIGURE 1. Localities of Hat Creek amber and other fossil sites mentioned in the text. 1, Hat Creek; 2 McAbee; 3, Princeton; 4, Nanaimo.

and Hymenoptera], Arachnida, Nematoda, and plants (Fig. 6). These include the oldest recorded fossils of terrestrial free-living nematodes. Ants (Hymenoptera: Formicidae) thus far identified in these deposits (both workers and alates) are extinct species of the genera *Technomyrmex* Mayr 1872 (Fig. 2), *Dolichoderus* Lund 1831, and *Leptothorax* Mayr 1855 (Fig. 4) (C. Baroni Urbani, personal communication).

Discussion

The present study provides evidence that *Agathis* survived the Cretaceous–Tertiary extinction event in the Northern Hemisphere and was a significant element in western North American forests in the Early Paleocene. There are no extant species of *Agathis* in the Northern Hemisphere; all are restricted to the Southern Hemisphere today (Whitmore 1980). The presence of *Agathis* in the Pacific Northwest during the early Tertiary is supported by araucarian megafossils: an extinct species of *Araucaria* Jussieu 1789 was described previously from the Middle Eocene McAbee Beds, not far from the Hat Creek coal locality in British Columbia (Verschoor 1974).

Other studies of fossil resins have indicated that *Agathis* was an important forest component in the Northern Hemisphere in the Mesozoic and that it produced all of the Cretaceous amber in western North America (Lambert *et al.* 1990, 1996). Megafossils of araucarians which could be *Agathis* or a closely related genus have also been reported from Cretaceous deposits in the Pacific Northwest. In a synopsis of the flora of the Upper Cretaceous Nanaimo Group of Vancouver Island, Bell (1957) described fossils (*Dammarites* Presl 1838) that resemble living *Agathis*. Other Pacific Northwest sites with araucarian megafossils include the Lower Cretaceous Spences Bridge Group of the Princeton area in British Columbia (Rice 1947).



FIGURES 2–7. Representative life forms in Hat Creek amber. 2. A worker ant of the genus *Technomyrmex*. Scale bar = 0.4 mm. 3. A cockroach of the subfamily Corydiinae (Polyphagidae). Scale bar = 1.0 mm. 4. A worker ant of the genus *Leptothorax*. Scale bar = 0.42 mm. 5. A thrips (Thysanoptera). Scale bar = 0.17 mm. 6. Portion of a bryophyte. Scale bar = 0.45 mm. 7. A beetle larva (Coleoptera). Scale bar = 0.17 mm.

(Atkinson *et al.* 1991). There are no native cockroaches in western Canada today (Kevan 1979). These and other amber insects indicate a subtropical to tropical climate in the Pacific Northwest some 50–55 million years ago, which is supportive of previously derived conclusions from analyses of fossil plants assemblages from this period and locality (Verschoor 1974; Hopkins 1980; Wilson 1996).

Acknowledgments

We would like to thank Mark Winston and the Biology Department, Simon Fraser University, for financial assistance, The British Columbia Paleontological Alliance for providing a Research Site Reserve permit, Mayumi Kariya of British Columbia Hydro for granting access permission, Dave Langevin for providing specimens for this study, J.B. Lambert and C.E. Shawl for the NMR spectra, and Shelley Dowson, Mark Winkler, and Brain Jackson for assistance at the site. We thank C. Baroni Urbani for determining the Hat Creek ant specimens and supplying information from his cladistic analysis of the Apocrita concluding that the New Jersey "ant" fossils are much closer to wasps than to true ants of the family Formicidae.

References

Agosti D, Grimaldi D, Carpenter JM. 1998. Oldest known ant fossils discovered. *Nature (London)* **391**: 447.

Atkinson TH, Koehler PG, Patterson RS. 1991. Catalog and atlas of the cockroaches (Dictyoptera) of North America north of Mexico. *Miscellaneous Publications of the Entomological Association of America* **78**.

Baroni Urbani C. 1989. Phylogeny and behavioral evolution in ants. *Ethology, Ecology and Evolution* **1**: 137–68.

Bell WA. 1957. Flora of the Upper Cretaceous Nanaimo Group, Vancouver Island. *Geological Survey of Canada Memoir* **293**.

Brandao CRF, Baroni Urbani C, Wagensberg J, Yamamoto CI. 1999. New *Technomyrmex* in Dominican amber (Hymenoptera: Formicidae), with a reappraisal of the Dolichoderinae phylogeny. *Entomologica Scandinavica*. In press.

Carpenter FM. 1929. A fossil ant from the Lower Eocene (Wilcox) of Tennessee. *Journal of the Washington Academy of Science* **19**: 300–301.

——— 1930. The fossil ants of North America. *Bulletin of the Museum of Comparative Zoology* **70**: 1–66.

——— 1992. Superclass Hexapoda. pp. 1–655 *in* RL Kaesler (Ed), Treatise on invertebrate paleontology: Arthropoda 4 (4). The Geological Society of America, Boulder, CO, and the University of Kansas, Lawrence, KS.

Cockerell TDA. 1921. Some Eocene insects from Colorado and Wyoming. *Proceedings of the United States National Museum* **59**: 29–39.

Church BN. 1975. Geology of the Hat Field Creek Coal Basin. pp. 99–118 *in* Fieldwork 1975. *British Columbia Ministry of Energy, Mines and Petroleum Resources Paper* **921/13E**.

——— 1981. Further studies of the Hat Creek coal deposit. pp. 73–77 *in* Geological Fieldwork 1980. *British Columbia Ministry of Energy, Mines and Petroleum Resources Paper* **1981-1**.

Church BN, Matheson A, Hora ZD. 1979. Combustion metamorphism in the Hat Creek area, British Columbia. *Canadian Journal of Earth Sciences* **16**: 1882–87.

Dlussky GM. 1975. Formicidae. pp. 115–121 *in* AP Rasnitsyn (Ed.), Hymenoptera Apocrita of the Mesozoic. *Transactions of the Paleontological Institute of the Academy of Sciences of the USSR* **147**. [In Russian.]

Grand L. 1984. Paleontology of the Green River Formation, with a review of the fish fauna. 2nd ed. *Bulletin of the Geological Survey of Wyoming* **63**: 1–333.

Grimaldi D, Agosti D, Carpenter JM. 1997. New and rediscovered primitive ants (Hymenoptera: Formicidae) in Cretaceous amber from New Jersey, and their phylogenetic relationships. *American Museum Novitates* **3208**.

Hong Y-C, Yang T-C, Wang S-T, Wang S-E, Li Y-K, Sun M-R, Sun H-C, Tu N-C. 1974. Stratigraphy and paleontology of Fushin Coal field, Liaoning Province. *Acta Geologica Sinica* **2**: 113–49.

Hopkins WS Jr. 1980. Palynology of the 75-106 B.C. Hydro core hole, Hat Creek Coal Basin, British Columbia. *Geological Survey of Canada Open File* **547**.

Johnston JE. 1993. Insects, spiders, and plants from the Tallahatta Formation (Middle Eocene) in Benton County, Mississippi. *Mississippi Geology* **14**: 71–82.

Kevan DK McE. 1979. Dictuoptera. pp. 314–16 *in* HV Danks (Ed.), Canada and its insect fauna. *Memoirs of the Entomological Society of Canada* **108**.

Lambert JB, Frye JS, Poinar GO Jr. 1990. Analysis of North American amber by carbon-13 NMR spectroscopy. *Geoarchaeology* **5**: 43–52.

Lambert JB, Johnson SC, Poinar GO Jr. 1996. Nuclear magnetic resonance characterization of Cretaceous amber. *Archaeometry* **38**: 325–35.

Lambert JB, Johnson SC, Poinar GO Jr, Frye JS. 1994. Recent and fossil resins from New Zealand and Australia. *Geoarchaeology* **8**: 141–55.

Lutz H. 1986. Eine neue Unterfamilie der Formicidae (Insecta: Hymenoptera) aus dem mittel-eozanen Olschiefer der "Grube Messel" bei Darmstadt (Deutschland, S- Hessen). *Senckenbergiana Lethaea* **67**: 177–218.

McAlpine JF, Martin JEH. 1966. Canadian amber — a paleontological treasure chest. *The Canadian Entomologist* **101**: 818–39.

Pike EM. 1995. Amber taphonomy and the Grassy Lake, Alberta, Amber fauna. Ph.D. thesis, The University of Calgary, Calgary, AB.

Poinar GO Jr. 1992. Life in amber. Stanford University Press, Stanford, CA.

Rice HMA. 1947. Geology and mineral deposits of the Princeton map-area, British Columbia. *Geological Survey of Canada Memoir* **243**.

Verschoor K van Romondt. 1974. Paleobotany of the Tertiary (early Middle Eocene) McAbee Beds, British Columbia. M.Sc. thesis, The University of Calgary, Calgary, AB.

Wheeler WM. 1914. The ants of the Baltic amber. *Schriften Physikalisch- Okonomischen Gesellschaft zu Konigsberg* **55**: 1–142.

Whitmore TC. 1980. A monograph of *Agathis*. *Plant Systematics and Evolution* **135**: 44–69.

Wilson EO. 1985. Ants from the Cretaceous and Eocene amber of North America. *Psyche* **92**: 205–16.

Wilson EO, Carpenter FM, Brown WL. 1967. The first Mesozoic ants, with the description of a new subfamily. *Psyche* **74**: 1–19.

Wilson MVH. 1996. Insects near Eocene lakes of the Interior. pp. 225–33 *in* R Ludvigsen (Ed.), Life in stone: a natural history of British Columbia's fossils. University of British Columbia Press, Vancouver, BC.

(Date received: 11 June 1998; date accepted: 25 September 1998)